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PIONEERING FACTORS DRIVING DIVERGING TYRE TECHNOLOGY FROM CONVENTIONAL TYRES TO NON-PNEUMATIC TYRES

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ABSTRACT

Non-Pneumatic Tires (NPT) are tyres that are not pneumatically inflated and are supported by flexible spokes and a closed construction. Several important reasons to upgrade from traditional tyres include maintaining the correct composition of internal air, avoiding excessive wear and tear, and avoiding unexpected damage. Several significant considerations to consider when selecting non-pneumatic tyres are their high rolling resistance, inability to flatten, and minimal maintenance. The combination of elastic polymer and composite materials results in excellent performance, and the asymmetric design enables non-pneumatic tyres to fulfil a variety of jobs, providing them an advantage over traditional tyres. The strength of the NPT is determined by its form and structure, and there are many shapes and structures available for different purposes. Cost savings are achieved via the design of spoke structures and the efficient manufacturing of components. Airless tyres should improve by designing spokes in such a manner that the weight distribution is uniform, the cushioning effect is enough for appropriate vibration damping and vehicle dynamics stability, and there is no debris trapped between the spokes. The drawbacks of non-pneumatic tyres include heat build-up in the tyres and reduced suspension, which results in decreased driver and passenger comfort. This article will mainly discuss the many reasons that have contributed to the shift away from traditional tyres toward airless tyres. The issues discussed include the advantages of the NPT over traditional tyres and the disadvantages that must be addressed in the future via the adaptation of different architectures, forms, and manufacturing methods.

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Original Article

INTRODUCTION

Robert William Thomson developed the first pneumatic tyre. There were several different factors that were responsible for the development of airless tyres, such as manufacturing, abrupt damage, and monitoring air pressure[7]. Tim Rhyne and Steve Cron are two of the world's leading researchers and designers of non-pneumatic tyres. The reduced weight of these airless tyres helps to decrease fuel costs. Components like deformable wheels, tread, flexible spokes, and shear bands are often utilised for improved construction and weight distribution, with no issues. One advantage of composite materials and elastic polymers in pneumatic tyres is that they alleviate the issues associated with pneumatic tyres. The simulation and analysis of NPT are done by assuming the airless tire as curved beam and apply Euler-Bernoulli beam assumption to develop a design of the NPT [1]. Flexible spokes are more flexible and provide more energy and stress absorption. Shear bands and tread assist in momentarily deforming and rapidly returning to its original shape. This compensates the traditional tyre for these components.With these parts in place, the tyres are in balance. Tires without pneumatic support are mostly

employed in vehicles used for transportation and heavy load carrying. They have high-stability and provide a smooth ride. As these airless tyres are unlikely to wear out, there is less risk of tyre wear and tear. But although there is a risk of the airless tyre growingin size as a consequence of heat build-up, the use of synthetic polymers helps somewhat. Bridgestone and Michelin have thoroughly researched airless tyres, and these firms have developed new and improved versions. Non-pneumatictyres have a wide range of use in the military, space, cars, and many other industries [13]. It is because of the tire's inability to flatten, with there being no way of getting a puncture, that allows the rovers to explore the moon and space.

DISCUSSIONS

1. Components and Structures of Spokes

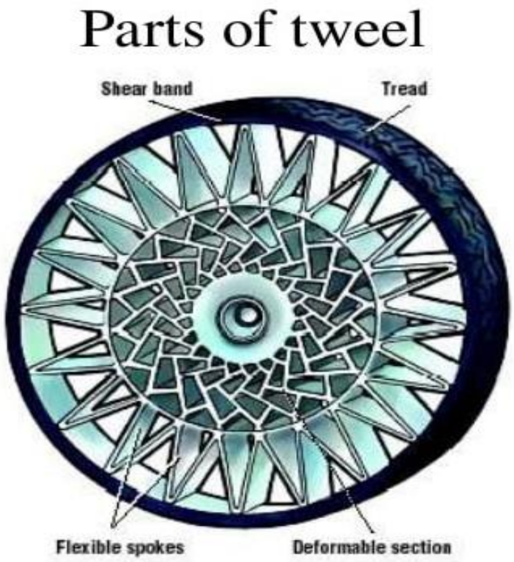

Figure 1: Represents the Parts of a Typical Tweel

The spokes, shear band, hub, and tread band are the four major components of airless tyres. The shear ring is made up of a shear band as well as inner and outer membranes. The shear band exists between the two membranes [6]. The shear band is subjected to cyclic shear stress while rolling. As a result, this shear ring aids in the efficient distribution of stress throughout the structure during material deformation. The use of a porous shear band helps to reduce rolling resistance, which in turn helps to reduce fuel costs. The air pressure in the traditional tires was replaced by spokes strength and tension possessed by the band.The spoke structures' primary goal is to improve the performance of airless tyres. In traditional tyres, the strength of the spokes and the tension of the shear band on the spokes replace air pressure in conventional tyres. The failure of spokes of airless tires occurs due to fatigue stress developed in the spokes and to avoid failure of spokes we need to lower shear stress in the spoke [3]. The constructions that will be covered in this article include the aluminium honeycomb structure, the wedge structure, the diamond structure, and the traditional tyre [10].

The honeycombs are created using beam theory. The stress strain curves in honeycomb structures vary based on the cellular geometry [6]. This construction will have a high torsional stiffness but a low lateral stiffness. The cell structure of honeycombs is adjustable to optimize in-plane properties, for instance by changing the cell angle, wall thickness, and length to produce tailored stiffness and strength [5]. The structural analysis of airless having spokes made of hexagonal structures with same cell wall thickness produced the results of spoke with larger cell angle showed minimum stress

concentration which is significant for fatigue resistant designs, ratio of inclined cell angle to cell height is a crucial determinant which shows the flexibility of honeycomb structure under axial loading. High ratio includes more flexibility to structure [18]. The tread band, which is helpful for grip, is an important component in meeting the road. Bridgestone is developing wedge spoke architectures and has released these tyres. These spoke structures aid in efficient spoke flexing without twisting. These tyres are having high stiffness and have a low rolling resistance. Diamond spokes are better for stress absorption, load distribution, and durability. Load bearing capacity is one of the important factors in the process of design of NPTs, which can be characterized by displacement of the hub centre [5]. To choose the best spoke constructions, deflection, spoke modulus, spoke curvature, and von-misses stresses should be analysed and studied. Tread aids in achieving great traction by using a shear band and flexible spokes, which is particularly helpful while travelling over terrain and uneven surfaces [9]. The increase of thickness of the shear band makes the NPT more rigid and thereby increases the stiffness of the structure and when the thickness of the shear band increases more volume of material is subjected to the vertical load [2]. The expected vertical stiffness value of pneumatic tire can be evaluated using simplified Rhyne’s equation as expressed in Equation.

$$K_z = 0.00028P\sqrt{W \times OD} + 3.45$$

Where Kz is the vertical stiffness, P is inflation pressure, W is tread or footprint width, and OD is the overall diameter.

The results of dynamic impact simulation of the interaction between non pneumatic tires and sand with obstacle, the numerical simulation shows that the lower running speed deforms the non-pneumatic tire much more than the higher running speed does. The higher running speed generates higher contactpressure peaks than the lower running speed does, and the resulting contact pressure is not uniform [16]

2. MATERIALS USED FOR COMPONENTS

2.1. For Pneumatic Tires

Figure 2: Pneumatic Tire

The basic function of the tire can be concluded to provide the vehicle to road interface, to support vehicle load, to absorb road irregularities, and to provide road surface friction. Cords are often used to maintain the form of a tyre [8]. It aids in the control of inflation pressure by giving the necessary tensile strength. These are mostly composed of aramid, nylon, and a few other materials. For keeping them together and protecting them from wear, elastomers such as ethylene

propylene rubber and styrene butadiene rubber are employed.

2.2. For non-Pneumatic Tires

Figure 3: Non-Pneumatic Tire.

High-elastic polymers are utilised to make the spokes. Polyurethane is utilised for spokes because of its ability to rapidly return to its original shape after deformation and its high weight carrying capability. Polyurethane offers excellent wear, tear, and heat resistance. The two inextensible membranes are made of strength steel, to strength the shear band, and the three make a shear beam [15]. The tread band is made of rubber. Rubber vulcanization improves the strength, grip, and longevity of the tread by creating connections between the components, making it more difficult to break. Shear bands are often made of syntactic rubber. It is very beneficial in terms of performance and cornering stiffness. The hub is mostly composed of aluminium alloy or steel. The mass of NPTs is a pivotal factor that need to minimize to reduce energy consumption [5]. The typical weight of an aluminium alloy is 2 to 3 kg, while steel is 4 kg. These materials contribute to excellent strength and rigidity. The use of a flexible, high-strength resin as a material improves driving performance and load carrying capacity. There is a strong chance of high-speed travel in light cars with them. The NPTs when more volume of material in the shear band is used, the NPT becomes more resistant to shear effect and less energy is lost while rolling [2]. Physical testing on a test rack with a travelling platform yields superior findings for tyre analysis [11]. The results of aluminium tapper brittle shaped shear band for an airless tire is obtained to be multiple bristle elements that behaves as a whole, homogenous material with good material properties. The bristles were modelled with a tapered geometry that efficiently distributed deformation and stresses throughout the bristle length to allow for high stiffness and high compliance simultaneously [17].

Table 1: Materials and their Properties Table

Part	**Spokes**	**Shear Band**	**Hub**	**Outer Ring**
Material	**Polyurethane**	**Rubber**	**Aluminum alloy**	**ANSI 4340**
Elastic Modulus E (Mpa)	32	14	2800	210000
Yield Strength, (Mpa)	145	17	440	470
Shear Modulus, G (Mpa)	11.08	3.5	26.9	-----
Poisson'sratio, N	0.47	0.48	0.33	0.29
Density, ρ (kg/m3)	1220	1049	2800	7800

When compared to normal tyres, the design and production of airless tyres is much more complicated. Despite their complexity, non-pneumatic tyres have several benefits over traditional tyres.

3. FACTORS TO BE CONSIDERED FOR THE DESIGNING OF AIRLESS TIRE

Heat dissipation is an essential tyre characteristic that refers to the heat generated by friction between the tyre and the road surface. Heat dissipation is more efficient in airless tyres than in traditional tyres. Airless tyres are more effective in heat dissipation since there is no air and no pressure differences are generated. The heat dissipation coefficient is determined by the tyre material's coefficient.

Vibration damping capability is required for vehicle dynamics balance and control [11]. The vibration damping capability is determined by the stiffness coefficient of the tyre and the elasticity of the material employed. The elasticity and stiffness coefficients of airless tyres may be changed by modifying the material characteristics. By changing the material characteristics, the damping capacity of airless tyres may be increased [9].

There are many design concerns while creating a tyre. Load capacity, cushioning effect, wear and abrasion resistance and traction, cutting and tearing resistance, high speed operation, and chemical resistance are all factors to consider. There are some design variables need to consider for NPT such as thickness of spokes, the shear band thickness and shear modulus of shear band and spokes of NPT [2]. The characteristics of a non-pneumatic tyre are determined by its construction, material, and manufacturing process.

4. MANUFACTURING TECHNIQUES

The factors evaluated to produce airless tyres have an impact on the manufacturing method [9]. The criteria include tyre size, spoke shape, tyre material, heat dissipation capability, vibration damping capacity, tyre wear and tear, tyre anticipated life, and design considerations, which lead to the selection of an efficient and affordable production process.

4.1. Extrusion

Manufacturing is a critical step in the creation of airless tyres. Non-pneumatic tyres are made up of several components. Polyurethane was used to construct honeycomb spokes and shear band, while synthetic rubber was for the thread [5]. The

airless tyres are made by combining tread and shear band creation, hub creation, and hub assembly with polyurethane spokes. Non-Pneumatic Tires are composed of solid rubber that is produced via the extrusion process. To create the required form, rubber is heated and pushed through a die. A typical airless tyre is made up of the following components.

Table 2: Components and their Manufacturing Methods Table

Sl.no	Component	Manufacturing Methods
1.	Flexible spokes	Melting and casting
2.	Shear band	Reinforcement of polyurethane material
3.	Hub	Casting process
4.	Inner ring	Casting
5.	Outer ring	Casting
6.	Tread band	Reinforcement into shear bond

Figure 4: Typical Manufacturing Process of Tire.

4.2. Reinforcement Method

Non-pneumatic tyres may be produced using different techniques. Solid rubber is used to make solid airless tyres [14]. This is the most used production technique for tyres in the business. The elastic polyurethane high adhesiveness to properly prepared band material surfaces ensure the robust and dependable connections of a disc wheel and a tyre. The hub, outer and inner rings are made using the casting technique. Because of its excellent elasticity and thermoplastic processing, thermoplastic polyurethane (TPU) is a desired material to replace rubber materials in the production of high-performance tyres.

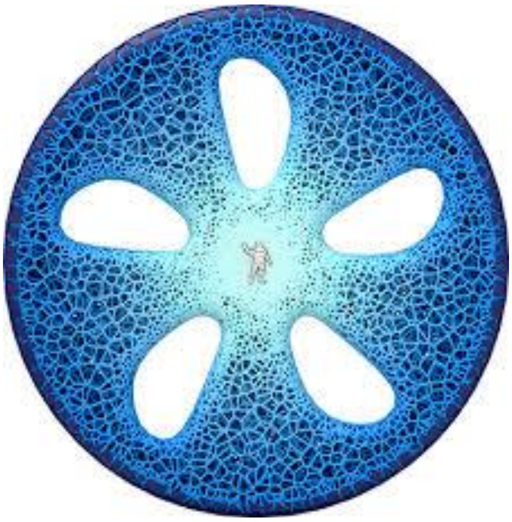

Figure 5: 3D Printed non-Pneumatic Tire.

4.3. 3D Printing Method

Emerging research is being conducted in airless tyre production utilising additive manufacturing technology (3D printing) [12]. Through the FDM printing technique, the advancement of 3D printing technology is opening the way for the development of complex structures in airless tyres. Non-pneumatic tyre design and manufacturing may enhance design characteristics as well as wet skid resistance. Each component of the airless tyre must be developed and manufactured independently before being combined.

Future Scope

Some of the areas where research is being conducted include tyre noise, anticipated life, and tyre wear and tear. These problems must be addressed by offering a viable solution. Although the life of airless and pneumatic tyres is the same, airless tyres are more costly. Researchers are trying to create an efficient manufacturing technique, and 3D printing technology is being considered. A typical non-pneumatic tyre is less harmful to the environment than a traditional tyre. Polyurethane wheel, solid tire and auxiliary supporting wheel have the disadvantage of more weight and poor mobility, and do not apply to vehicles. To solve the above problems, a mechanical elastic wheel (MEW) for an off-road vehicle was proposed. The results indicate small rolling resistance, good traffic ability and other good characteristics [4].

CONCLUSIONS

Airless tyres aid in overcoming the problems associated with the usage of traditional tyres. Several leading corporations are actively researching and implementing non-pneumatic tyres.These have a wide range of uses in a variety of areas. Manufacturing and design difficulties, as well as heat build-up in tyres, are a few of the issues that need study to address. Airless tyres have a large capacity for development. There is now a lot of study going on in industry R&D departments to discover an effective method to prevent air trapping in between the spokes and continuous transfer of loads with uniform distribution.

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